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(54) **Forming ceramics films by anode-spark discharge in electrolytic bath**

(57) The electrolytic bath comprises an aqueous solution of a water-soluble or colloidal silicate and/or an oxyacid salt to which ceramics fine particles and/or specific fine particles are dispersed and the spark discharge is carried out in the electrolytic bath while ensuring the suspended state of the ceramics particles and/or the specific fine particles in the electrolytic bath. The method makes it possible to effectively form, on the surface of a metal substrate, ceramics films having a variety of color tones as well as excellent insulating properties and hardness. Moreover, it further makes it possible to effectively form a composite ceramics film having excellent wear resistance on the surface of a metal substrate.

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Method for Forming Ceramics Films by Anode-Spark  
Discharge

The present invention relates to a method for forming a ceramics film on the surface of a metal substrate through anode-spark discharge and more specifically to a method for co-depositing fine ceramics particles and/or specific fine particles with ceramics components dissolved in the bath on the surface of a metal substrate by performing the spark discharge in a bath comprising a suspension containing these particles.

Ceramics films formed through an anode-spark discharge technique exhibit various excellent properties such as electrical insulating properties, low outgassing properties under ultra-high vacuum, corrosion resistance, flexibility and adhesion and, therefore, the spark discharge technique has become a center of attention as a technique for forming films.

Under such circumstances, there have been a variety of patents which relate to techniques for forming films by use of the spark discharge. For instance, U.S. Patent Nos. 3,822,293; 3,834,999 and 4,082,626 disclose methods for forming films which comprise dissolving an alkali metal silicate or an alkali metal hydroxide or a combination of such an alkali with an oxyacid catalyst in water and performing spark discharge in the aqueous solution. In addition, Japanese Patent Publication for Opposition Purposes (hereunder referred to as "J.P. KOKOKU") No. Sho 58-17278 discloses a method for forming a film by use of an electric current having a specific wave form, which makes it possible to form a protective film on the surface of an aluminium substrate in an efficiency more higher than that achieved by the foregoing methods disclosed in the U.S. Patents. J.P. KOKOKU Nos. Sho 59-28636 and Sho 59-45722 also disclose methods for

forming a colored protective film having a variety of color tones on an aluminium substrate, in which a metal salt or the like is added to an electrolytic bath.

On the other hand, J.P. KOKOKU No. Sho 59-28637  
5 discloses a method for effectively forming a film on a magnesium or alloy substrate by use of an electric current having a specific wave form and J.P. KOKOKU No. Sho 59-28638 discloses a method for forming a  
10 protective film having a variety of color tones.

The foregoing methods disclosed in the  
10 aforementioned patents make it possible to form films having the foregoing characteristics, but the resulting films have low hardness, insufficient dielectric  
15 breakdown voltage and low film-forming velocity depending on the kinds of the electrolytic bath. In other words, these methods are not practical.

Accordingly, a primary object of the present invention is to provide a method for effectively  
20 forming, on the surface of a metal substrate, ceramics films having a variety of color tones as well as excellent insulating properties and hardness by anode-spark discharge.

Another object of the present invention is to provide a method for effectively forming a composite  
25 ceramics film having excellent wear resistance on the surface of a metal substrate by anode-spark discharge.

These and other objects of the present invention will be clear from the following description and  
30 Examples.

The present invention has been completed on the basis of the finding that the foregoing objects of the present invention can effectively be achieved if fine  
35 ceramics particles and/or specific fine particles are suspended in an electrolytic bath for forming a ceramics film on a metal substrate by anode-spark discharge and these suspended particles are deposited

on the substrate simultaneously with components of the electrolytic bath.

According to a first aspect of the present invention, there is provided a method for forming a ceramics film on the surface of a substrate by spark discharge performed in an electrolytic bath, wherein the electrolytic bath comprises an aqueous solution of a water-soluble or colloidal silicate and/or an oxyacid salt to which ceramics fine particles are dispersed and the spark discharge is carried out in the electrolytic bath while ensuring the suspended state of the ceramics particles in the electrolytic bath.

According to a second aspect of the present invention, there is provided a method for forming a ceramics film on the surface of a substrate by spark discharge performed in an electrolytic bath, wherein the electrolytic bath comprises an aqueous solution of a water-soluble or colloidal silicate and/or an oxyacid salt, to which fine particles of a member selected from the group consisting of molybdenum disulfide, carbon, fluorinated graphite and tetrafluoroethylene resin are dispersed and the spark discharge is carried out in the electrolytic bath while ensuring the suspended state of the fine particles in the bath.

The electrolytic bath used in the present invention is a dispersion comprising an aqueous solution containing a water-soluble or colloidal silicate and/or at least one oxyacid salt selected from the group consisting of tungstates, stannates, molybdates, borates, aluminates, phosphates or the like, to which fine particles of ceramics are dispersed. To the electrolytic bath, there may be added metal ions such as Ni, Co, Zn, Ca, Ba, Mg, Pb or Cr ions or mixture thereof in the form of a water-soluble salt. Examples of the silicates are a variety of water-soluble ones represented by the general

formula:  $M_2O \cdot nSiO_2$  (wherein M represents an alkali metal and  $n$  is a positive number ranging from 0.5 to 100) such as sodium silicate, potassium silicate, lithium silicate and those capable of being dispersed in water such as colloidal silica. These silicates may be used alone or in combination.

The concentration of the silicate and/or the oxyacid salt in the aqueous solution used as the electrolytic bath in the invention is preferably not less than 5 g/l and more preferably 25 to 200 g/l, respectively. In particular, if an oxyacid salt is used in an amount almost equal to its saturation, the highest film-forming velocity can be achieved, but the resulting film is often non-uniform as the concentration thereof increases. For this reason, the concentration thereof is desirably limited to the range defined above. The pH value of the electrolytic bath is not particularly limited, but preferably ranges from 3 to 13.5

In the first aspect of the invention, various kinds of fine particles which are insoluble in the aqueous solution and capable of being dispersed therein can be used as the ceramics fine particles to be added to the aqueous solution. Specific examples thereof include oxide type ceramics such as  $Al_2O_3$ ,  $Al(OH)_3$ ,  $SiO_2$ ,  $3Al_2O_3 \cdot 2SiO_2$ ,  $TiO_2$ ,  $ZrO_2$  and  $Cr_2O_3$  and non-oxide type ceramics such as  $SiC$ ,  $TiC$ ,  $TiN$ ,  $TiB$ ,  $ZrB$ ,  $BN$ ,  $WC$ ,  $WSi_2$  and  $MoSi_2$ . These ceramics particles may be used alone or in combination.

The particle size of the ceramics particles desirably ranges from 0.03 to 100 $\mu$ m, in particular 0.03 to 20 $\mu$ m. That is, when the particle size thereof is increased, it is difficult to co-deposit the ceramics particles and if they are co-deposited the resulting film is non-uniform.

The amount of the fine particles of ceramics to be

added to the electrolytic bath can be arbitrarily determined depending on the kinds of the electrolytes in which the fine particles are dispersed and the amount of the fine particles to be dispersed, but is in  
5 general up to 200 g/l and most preferably ranges from 5 to 100 g/l from the viewpoint of the efficiency of the deposition.

Examples of the fine particles used in the second aspect of the present invention are molybdenum  
10 disulfide, carbon, fluorinated graphite, tetrafluoroethylene resin or mixture thereof. Graphite is preferable as a carbon component used herein. These fine particles have self-lubricating properties, are hence taken in the ceramics film during the spark  
15 discharge to thus give a film having good wear resistance.

In this embodiment, the ceramics fine particles used in the first aspect of the invention can be used together with the fine particles having self-  
20 lubricating properties.

The particle size of the fine particles having self-lubricating properties desirably ranges from 0.01 to 100  $\mu\text{m}$  and preferably 0.03 to 20  $\mu\text{m}$ . That is, when the particle size thereof is increased, it is difficult  
25 to co-deposit the ceramics particles and if they are co-deposited the resulting film is non-uniform.

The amount of the fine particles having self-lubricating properties to be added to the electrolytic bath can be arbitrarily determined depending on the  
30 kinds of the electrolytes in which the fine particles are dispersed and the amount of the fine particles to be dispersed, but is in general up to 200 g/l and most preferably ranges from 5 to 100 g/l from the viewpoint of the efficiency of the deposition.

35 In the first and second aspects of the present invention, examples of the metal substrates on which a

ceramic film can be formed by the spark discharge technique include those made from aluminium and alloys thereof; zirconium, titanium, niobium, magnesium and alloys thereof.

5        When a film is formed on a metal substrate by spark discharge, the substrate must not be subjected to a particular pretreatment, but it is desirable to sufficiently clean the surface of the substrate through degreasing, etching, washing with an acid or the like.

10        An insoluble electrode is used as a cathode and the cathode may be formed from, for instance, iron, stainless steel, nickel or the like.

15        In the method of the present invention, the spark discharge is carried out in the electrolytic bath defined above while ensuring the suspended state of the ceramic particles in the electrolytic bath. The ceramic fine particles sediment due to the gravitational action or the self-weight and thus it is important to conduct the spark discharge while  
20        maintaining the suspended state of the particles in the usual manner. The retention of such suspended state can be performed by stirring or circulation of the electrolyte.

25        When fine particles having poor dispersion properties are employed, there may be used a dispersant, for instance, a surfactant such as cationic, non-ionic, or anionic ones for obtaining a good dispersion.

30        The temperature of the electrolytic bath during the spark discharge in general ranges from 5 to 90°C and preferably 15 to 60°C. This is because, if it is too low, the film-forming velocity by the spark discharge is low, while if it is too high, it is liable to form a non-uniform film.

35        In addition, if the current density used is too low, the fine particles are hardly deposited, while if

it is too high, a film having a low particle density or a coarse film is formed at high current portions. Therefore, the current density preferably ranges from 0.2 to 20 A/dm<sup>2</sup>, more preferably 1 to 5 A/dm<sup>2</sup>.

5       The output from a power supply may be a direct current having any wave form, but preferably those having pulse shape (rectangular wave form), saw-tooth wave form or DC half-wave form.

10       The spark discharge-initiating voltage varies depending on various factors such as the wave form of the output current from the dc power supply, the concentration of the silicate and that of the oxyacid salt and the temperature of the bath, but it desirably ranges from 50 to 200 V. Moreover, the voltage  
15       observed during the film formation is increased as the spark discharge proceeds and the final voltage sometimes exceeds 1,000 V.

20       The electrolysis time varies depending on the desired thickness of the resulting film. However, if the resulting film is thin, the film does not show the quality peculiar thereto. Therefore, the electrolysis must be performed for at least 5 minutes. In general, practically acceptable films having a thickness, for instance, ranging from 2 to 80μm can be obtained if the  
25       electrolysis is performed for 10 to 60 minutes.

30       According to the first aspect of the present invention, there can effectively be prepared metallic materials having ceramic films having high insulating properties, high hardness and a variety of color tones.

35       Low outgassing properties, corrosion resistance and fastness properties can be imparted to an apparatus for manufacturing semiconductor devices by applying a ceramics film onto the shroud or the chamber of a reaction vessel of the apparatus according to the method of this invention. Moreover, if an aluminium or aluminium clad copper conductors is provided with a



ceramics coating, there can be obtained an electric wire coated with the ceramics layer having high dielectric breakdown voltage in addition to high flexibility and whose coated layer is hardly broken even if the layer has a flaw.

According to the method of this invention, the color tone of the resulting films is rather white depending on the kinds of the fine particles used and, therefore, the method can also be useful as a whitening treatment for aluminium construction materials.

If a ceramics film is applied onto a container for cosmetics comprising an aluminium material according to the method of this invention, there can be obtained a container for cosmetics having beautiful appearance of a variety of color tones and free of hit marks.

In addition, if a ceramics film is applied onto a heater of aluminium, a far infrared radiator having excellent far infrared emission properties and free of hit marks can be obtained.

The second aspect of the present invention makes it possible to effectively produce metallic materials having a ceramics composite layer thereon excellent in wear resistance.

Thus, if the composite film of the present invention is, for instance, applied onto sliding faces of movable portions in a vacuum vessel, an apparatus having excellent gas discharge properties, corrosion resistance and durability can be obtained. Moreover, if it is applied onto the sliding faces of movable portions of an apparatus, the apparatus operated at a high temperature is made heat resistant, corrosion resistant and durable.

Further, if the ceramics composite film is used as a coating for electric wires used in a vacuum or a radiation atmosphere, signal lines or the like which are excellent in gas discharge properties and corrosion

resistance and which is hardly damaged due to wearing such as friction can be obtained.

The far infrared radiation properties of the ceramics films can be further enhanced by incorporation of carbon into the films and, therefore, such films can be used for obtaining heaters having more excellent far infrared radiation properties. In addition, the appearance of the resulting films becomes black by the incorporation of carbon into the ceramics films and, therefore, this can be used for ornamental purposes.

The present invention will hereinafter be explained in more detail with reference to the following non-limitative working Examples and the effects practically attained by the invention will also be discussed in comparison with Comparative Examples given below.

Example 1

An aluminium plate was degreased, etched with an alkali and activated with an acid to clean the plate. Spark discharge was carried out in a suspension obtained by suspending a silicate fine particles (available from Tokuyama Soda Co., Ltd. under the trade name of FINE SHEEL E-50 having an average particle size of  $2.0\mu\text{m}$ ) in an aqueous solution of  $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$  (70 g/l) in an amount of 15 g/l, using the aluminium plate as an anode and a stainless steel plate as a cathode. In this stage, the electrolyte was sufficiently stirred so as not to cause sedimentation of the silicate fine particles to thus ensure a good suspended state thereof. The spark discharge was continued at a current density of  $3 \text{ A/dm}^2$  and a temperature of  $50^\circ\text{C}$  for 20 minutes to give a film having a thickness of  $35\mu\text{m}$ . The film was analyzed by an X-ray microanalyzer. As a result, the presence of Si, O, B and Na was detected. This indicates that a ceramics film containing a silicate was certainly formed.

Example 2

An electric current was passed, at a current density of  $1 \text{ A/dm}^2$  for 20 minutes, through the same anode and cathode used in Example 1 dipped in a dispersion obtained by suspending 20 g/l of  $\text{Al}_2\text{O}_3$  fine particles (available from SHOWA DENKO KK. under the trade name of LOW SODA ALUMINA AL-45A, the average particle size thereof =  $1.1\mu\text{m}$ ) in a 200 g/l aqueous solution of  $\text{K}_2\text{O} \cdot n\text{SiO}_2$  maintained at  $50^\circ\text{C}$ . As a result, a spark discharge was caused on the anode surface and thus a film having an average thickness of  $31\mu\text{m}$  was obtained. During the spark discharge, the suspended state of the fine particles was ensured in the same manner as in Example 1.

Example 3

An electric current was passed, at a current density of  $3 \text{ A/dm}^2$  for 30 minutes, through the same anode and cathode used in Example 1 dipped in a dispersion obtained by suspending 20 g/l of the same  $\text{Al}_2\text{O}_3$  fine particles used in Example 2 in a 70 g/l aqueous solution of  $\text{Na}_4\text{P}_2\text{O}_7 \cdot 10\text{H}_2\text{O}$  maintained at  $50^\circ\text{C}$ . As a result, a spark discharge was caused on the anode surface and thus a film having an average thickness of  $28\mu\text{m}$  was obtained. During the spark discharge, the suspended state of the fine particles was ensured in the same manner as in Example 1.

Example 4

An electric current was passed, at a current density of  $3 \text{ A/dm}^2$  for 20 minutes, through the same anode and cathode used in Example 1 dipped in a dispersion obtained by suspending 20 g/l of  $\text{Al}(\text{OH})_3$  fine particles (available from SHOWA DENKO KK. under the trade name of SAIRYU . BIRYU HYGILITE H-43, average particle size =  $0.6\mu\text{m}$ ) in a 70 g/l aqueous solution of  $\text{Na}_4\text{P}_2\text{O}_7 \cdot 10\text{H}_2\text{O}$  maintained at  $50^\circ\text{C}$ . As a result, a spark discharge was caused on the anode surface and thus a

film having an average thickness of  $27\mu\text{m}$  was obtained. During the spark discharge, the suspended state of the fine particles was ensured in the same manner as in Example 1.

5 Example 5

An electric current was passed, at a current density of  $3\text{ A/dm}^2$  for 30 minutes, through an anode which was a titanium plate cleaned by degreasing and etching with an acid and a cathode of stainless steel plate dipped in a dispersion obtained by suspending 20 g/l of the same  $\text{Al}_2\text{O}_3$  fine particles used in Example 2 in a 70 g/l of the same aqueous solution of  $\text{Na}_4\text{P}_2\text{O}_7 \cdot 10\text{H}_2\text{O}$  used in Example 3 maintained at  $50^\circ\text{C}$ . As a result, a spark discharge was caused on the anode surface and thus a film having an average thickness of  $36\mu\text{m}$  was obtained. During the spark discharge, the suspended state of the fine particles was ensured in the same manner as in Example 1.

The resulting film was analyzed by an X-ray microanalyzer and the presence of Ti, Al and P was detected. This indicates that a ceramics film containing Al fine particles was certainly formed.

Example 6

An electric current was passed, at a current density of  $1\text{ A/dm}^2$  for 30 minutes, through an anode which was an aluminium plate cleaned in the same manner as in Example 1 and a cathode of stainless steel plate dipped in a dispersion obtained by suspending 50 g/l of  $\text{Cr}_2\text{O}_3$  fine particles (available from Nippon Electric Industries, Ltd. under the trade name of ND-802, average particle size =  $0.7\mu\text{m}$ ) in a 80 g/l aqueous solution of  $\text{Na}_4\text{P}_2\text{O}_7 \cdot 10\text{H}_2\text{O}$  maintained at  $30^\circ\text{C}$ . As a result, a spark discharge was caused on the anode surface and thus a film having an average thickness of  $14\mu\text{m}$  was obtained. During the spark discharge, the suspended state of the fine particles was ensured in

the same manner as in Example 1. The resulting film was analyzed by an X-ray microanalyzer and the presence of Cr and O was detected. This indicates that a ceramics film containing Cr was certainly formed.

5 Example 7

Spark discharge was performed as in the same manner used in Example 6 except that the amount of  $\text{Na}_4\text{P}_2\text{O}_7 \cdot 10\text{H}_2\text{O}$  was changed to 60 g/l and that of  $\text{Cr}_2\text{O}_3$  fine particles to 70 g/l. As a result, a spark  
10 discharge was caused on the anode surface and thus a green film having an average thickness of  $15\mu\text{m}$  was obtained.

Example 8

An electric current was passed, at a current  
15 density of  $3 \text{ A/dm}^2$  for 30 minutes, through an anode which was an aluminium plate cleaned in the same manner as in Example 1 and a cathode of stainless steel plate dipped in a dispersion obtained by suspending 5 g/l of SiC fine particles (available from SHOWA DENKO KK.  
20 under the trade name of ULTRADENSIC DV A-2, average particle size =  $0.65\mu\text{m}$ ) in a 100 g/l aqueous solution of  $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$  maintained at  $40^\circ\text{C}$ . As a result, a spark discharge was caused on the anode surface and thus a film having an average thickness of  $28\mu\text{m}$  was  
25 obtained. During the spark discharge, the suspended state of the fine particles was ensured in the same manner as in Example 1. The resulting film was analyzed by an X-ray microanalyzer and the presence of Si and C was detected. This indicates that a  
30 ceramics film containing SiC was certainly formed.

Comparative Example 1

Spark discharge was generated in a 70 g/l aqueous solution of  $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$  using an aluminium plate which had been treated in the same manner as in Example  
35 1 and served as an anode and a stainless steel plate serving as a cathode under the same conditions used in

Example 1.

Comparative Example 2.

Spark discharge was generated in a 200 g/l aqueous solution of  $K_2O.nSiO_2$  using an aluminium plate which had been treated in the same manner as in Example 1 and served as an anode and a stainless steel plate serving as a cathode under the same conditions used in Example 2.

Comparative Example 3

Spark discharge was generated in a 70 g/l aqueous solution of  $Na_4P_2O_7.10H_2O$  using an aluminium plate which had been treated in the same manner as in Example 1 and served as an anode and a stainless steel plate serving as a cathode under the same conditions used in Example 3.

Various physical properties of the films obtained in Examples 1 to 8 and Comparative Examples 1 to 3 were measured. The results obtained are summarized in the following Table I.

In Table I, the film thickness, hardness, dielectric breakdown voltage and wear resistance of the films were determined according to the following methods.

Film Thickness

This was determined with an eddy-current type thickness meter, PERMASCOPE E 110B (available from Fischer Company).

Hardness

A test specimen was dried at 110°C for one hour, allowed to cool, the tip thereof was polished flat and smooth, a pencil whose tip had been sharpened was strongly pressed against the coated face at an angle of 45° and was moved on the face at a uniform velocity (3 cm/sec). The hardness of the film was expressed in terms of the hardness of the pencil at which the film was not broken in at least four measurements among five

runs in all.

Dielectric Breakdown Voltage

5 The dielectric breakdown voltage was determined with a dielectric breakdown voltmeter B-5110AF Type (available from Faice Co. Ltd) according to the varnish coating test method which is one of dielectric strength tests for solid electrical insulation materials (see JIS C2110).

Wear Resistance

10 A Suga abrasion tester (available from SUGA TESTER MANUFACTURING CO., LTD) was used for estimating the wear resistance of each film under the following conditions. In this test, previous abrasion was performed 100 ds (double strokes).

15

Abrasive strip : CC #400

Test cycle : 400 ds

Load: : 500 gf

Speed of friction movement : 40 ds

20

Wheel : rubber

Table I				
Example	Sub- strate	Composition of Electrolyte		
		Composition of Soluble Component	Concn. (g/l)	Fine Particle Component Concn. (g/l)
1	Al	$\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$	70	$\text{SiO}_2$ Fine Particles (av. particle size: 2.0 m) 15
2	Al	$\text{K}_2\text{O} \cdot \text{nSiO}_2$	200	$\text{Al}_2\text{O}_3$ Fine Particles (av. particle size: 1.1 m) 20
3	Al	$\text{Na}_4\text{P}_2\text{O}_7 \cdot 10\text{H}_2\text{O}$	70	ditto 20
4	Al	ditto	70	$\text{A}(\text{OH})_3$ Fine Particles (av. particle size: 0.6 m) 20
5	Ti	ditto	70	$\text{Al}_2\text{O}_3$ Fine Particles (av. particle size: 1.1 m) 20

/cont...



... /cont....

Table I

Composition of Electrolyte

Example	Sub- strate	Composition of Soluble Component	Concn. (g/l)	Fine Particle Component	Concn.
6	Al	ditto	80	Cr <sub>2</sub> O <sub>3</sub> Fine Particles	50
7	Al	ditto	60	Cr <sub>2</sub> O <sub>3</sub> Fine Particles	70
8	Al	Na <sub>2</sub> B <sub>4</sub> O <sub>7</sub> · 10H <sub>2</sub> O	100	SiC Fine Particles	5
Comparative Example	1	Al	Na <sub>2</sub> B <sub>4</sub> O <sub>7</sub> · 10H <sub>2</sub> O	70	---
	2	Al	K <sub>2</sub> O · nSiO <sub>2</sub>	200	---
	3	Al	Na <sub>4</sub> P <sub>2</sub> O <sub>7</sub> · 10H <sub>2</sub> O	70	---

Table I

Physical Properties of the Resulting Film						
Example	Substrate	Film Thickness ( $\mu$ )	Hardness (H)	Dielectric Break-down Voltage	Abrasion Resistance (ds/ m)	Color Tone
1	Al	34	7	320	64	White
2	Al	31	4	280	8	ditto
3	Al	28	7	320	67	ditto
4	Al	27	7	300	17	ditto
5	Ti	36	8	430	38	ditto

/cont...

Table I

## Physical Properties of the Resulting Film

	Sub- strate	Film Thickness (μ)	Hardness (H)	Dielectric Break- down Voltage	Abrasion Resistance (ds/ m)	Color Tone	
Example	6	A1	14	6	310	131	Black
	7	A1	15	7	280	156	Green
	8	A1	27	7	330	48	Pale Brown
Comparative Example	1	A1	14	5	240	42	White
	2	A1	25	3	240	5	ditto
	3	A1	18	6	270	57	ditto

As seen from the results shown in Table I, the films obtained in Examples 1 and 2 show hardness and dielectric breakdown voltage higher than those of the films obtained in Comparative Examples 1 and 2. It is likewise clear that the films obtained in Examples 3 to 8 have excellent properties compared with those of the film obtained in Comparative Example 3.

Example 9

An aluminium plate was degreased, etched with an alkali and activated with an acid to clean the plate. Spark discharge was carried out in a dispersion obtained by dispersing 3 g/l of fine particles of fluorinated graphite (available from Central Glass Co., Ltd. under the trade name of SEFBON having an average particle size of 2 $\mu$ m) in a 70 g/l aqueous solution of Na<sub>4</sub>P<sub>2</sub>O<sub>7</sub>·10H<sub>2</sub>O with the aid of 0.3 g/l of a non-ionic surfactant (available from Nikka Chemicals, Ltd., under the trade name of PELTEX 1225), using the aluminium plate as an anode and a stainless steel plate as a cathode. In this stage, the electrolyte was sufficiently stirred so as not to cause sedimentation of the fine particles of the fluorinated graphite to thus ensure a good suspended state thereof. The spark discharge was continued at a current density of 1 A/dm<sup>2</sup> and a temperature of 40°C for 60 minutes to give a film having a thickness of 10 $\mu$ m. The film was analyzed by an X-ray microanalyzer. As a result, the presence of Al, O, C and F was detected. This indicates that a ceramics film containing fluorinated graphite was certainly formed.

Example 10

With the same anode and cathode as those used in Example 9, spark discharge was carried out at a current density of 1 A/dm<sup>2</sup> and a temperature of 40°C for 60 minutes in a solution obtained by suspending 40 g/l of Al<sub>2</sub>O<sub>3</sub> fine particles (available from SHOWA DENKO KK.

under the trade name of REACTIVE ALUMINA AL-160SG having an average particle size of  $0.4\mu\text{m}$ ) and a sol in which 50 g/l of  $\text{MoS}_2$  fine particles (available from Hitachi Powder Metallurgy Co., Ltd. under the trade name of HITASOL MA-407S) are dispersed in 70 g/l aqueous solution of  $\text{Na}_4\text{P}_2\text{O}_7 \cdot 10\text{H}_2\text{O}$ . As a result, a composite film having an average film thickness of  $15\mu\text{m}$  was obtained and the presence of Al, O, Mo and S was detected by an X-ray microanalyzer. This indicates that molybdenum disulfide was co-precipitated.

Example 11

With the same anode and cathode as those used in Example 9, spark discharge was carried out at a current density of  $1\text{ A/dm}^2$  and a temperature of  $40^\circ\text{C}$  for 40 minutes in a solution obtained by suspending 40 g/l of  $\text{Al}_2\text{O}_3$  fine particles (available from SHOWA DENKO KK. under the trade name of REACTIVE ALUMINA AL-160SG) and a sol in which 50 g/l of graphite fine particles (available from Hitachi Powder Metallurgy Co., Ltd. under the trade name of AB-1D having an average particle size of  $1\mu\text{m}$ ) are dispersed in 70 g/l aqueous solution of  $\text{Na}_4\text{P}_2\text{O}_7 \cdot 10\text{H}_2\text{O}$ .

As a result, a composite film having an average film thickness of  $13\mu\text{m}$  was obtained and the presence of Al, O and C was detected by an X-ray microanalyzer. This indicates that graphite fine particles were surely co-deposited.

Example 12

With the same anode and cathode as those used in Example 9, spark discharge was carried out at a current density of  $1\text{ A/dm}^2$  and a temperature of  $30^\circ\text{C}$  for 40 minutes in a solution obtained by suspending 40 g/l of  $\text{Al}_2\text{O}_3$  fine particles (available from SHOWA DENKO KK. under the trade name of REACTIVE ALUMINA AL-160SG) in 70 g/l aqueous solution of  $\text{Na}_4\text{P}_2\text{O}_7 \cdot 10\text{H}_2\text{O}$  in which a sol containing 2 g/l of tetrafluoroethylene resin fine

particles (available from Central Glass Co., Ltd. under the trade name of CEFURAL LOOVE-I having an average particle size of 3 $\mu$ m) were further dispersed with the aid of a fluorine atom-containing non-ionic surfactant (available from DAINIPPON INK AND CHEMICALS, INC. under the trade name of Megafack F-142D) as a dispersant.

As a result, a composite film having an average film thickness of 14 $\mu$ m was obtained and the presence of Al, O, F and C was detected by an X-ray microanalyzer. This indicates that the tetrafluoroethylene resin fine particles were certainly co-deposited.

Comparative Example 4

With an aluminium plate which had been cleaned in the same manner used in Example 9 and served as an anode and a stainless steel plate serving as a cathode, spark discharge was performed in a 70 g/l aqueous solution of  $\text{Na}_4\text{P}_2\text{O}_7 \cdot 10\text{H}_2\text{O}$  under the same conditions used in Example 9.

The results obtained are listed in the following Table II.

Table II  
Composition of Electrolyte

Example	Substrate	Composition of Soluble Component	Concn. (g/l)	Ceramics Fine Particle Component	Concn. (g/l)	Self-Lubricating Fine Particle	Concn. (g/l)
9	Al	$\text{Na}_2\text{P}_2\text{O}_7 \cdot 10\text{H}_2\text{O}$	70			Fluorinated Graphite Fine Particles	3
10	Al	ditto	70	$\text{Al}_2\text{O}_3$ Fine Particles	40	$\text{MoS}_2$ Fine Particles	50
11	Al	ditto	70	$\text{Al}_2\text{O}_3$ Fine Particles	40	Sol of Graphite Fine Particles	10
12	Al	ditto	70	ditto	40	Tetrafluoroethylene Resin Fine Particles	2
Comparative Example 4	Al	ditto	70				

Table II  
Physical Properties of the Resulting Film

Example	Sub- strate	Film Thickness ( $\mu$ )	Hardness (H)	Dielectric Break- down Voltage	Abrasion Resistance (ds/ m)	Color Tone
9	Al	11	6	200	95	Pale Brown
10	Al	15	7	280	192	ditto
11	Al	13	7	230	154	ditto
12	Al	14	7	220	148	White
Com- parative Example	Al	10	6	260	39	ditto



CLAIMS:

1. A method for forming a ceramics film on the surface of a substrate by spark discharge performed in an electrolytic bath, wherein the electrolytic bath comprises an aqueous solution of a water-soluble silicate or colloidal silicate and/or an oxyacid salt, in which solution ceramics fine particles are dispersed and wherein the spark discharge is carried out in the electrolytic bath while ensuring that the ceramics particles are maintained in suspension in the electrolytic bath.

2. A method according to claim 1 wherein the oxyacid salt is a tungstate, stannate, molybdate, borate, aluminate or phosphate.

3. A method according to claim 1 or 2 wherein the silicate is selected from those silicates represented by the general formula:  $M_2O \cdot nSiO_2$  (wherein M represents an alkali metal and  $n$  is a positive number in the range of from 0.5 to 100) and those silicates capable of being dispersed in water.

4. A method according to claim 3 wherein the silicate is sodium silicate, potassium silicate, lithium silicate or colloidal silica.

5. A method according to any of claims 1 to 4 wherein the concentration of the silicate and/or the oxyacid salt in the aqueous solution used as the electrolytic bath is in the range of from 25 to 200 g/l, respectively.

6. A method according to any of claims 1 to 5 wherein the ceramic added to the aqueous solution is  $Al_2O_3$ ,  $Al(OH)_3$ ,  $SiO_2$ ,  $3Al_2O_3 \cdot 2SiO_2$ ,  $TiO_2$ ,  $ZrO_2$ ,  $Cr_2O_3$ ,  $SiC$ ,  $TiC$ ,  $TiN$ ,  $TiB$ ,  $ZrB$ ,  $BN$ ,  $WC$ ,  $WSi_2$  or  $MoSi_2$ .

7. A method according to any preceding claim wherein the particle size of the ceramics particles is in the range of from 0.03 to 100 $\mu$ m.

8. A method according to claim 7 wherein the

particle size of the ceramics particles is in the range of from 0.03 to 20 $\mu$ m.

9. A method according to any preceding claim wherein the amount of the fine particles of ceramics added to the electrolytic bath is in the range of from 5 to 100 g/l.

10. A method according to any preceding claim wherein the spark discharge is carried out at a bath temperature in the range of from 5 to 90°C and a current density in the range of from 0.2 to 20 A/dm<sup>2</sup> for not less than 5 minutes.

11. A method according to claim 10 wherein the spark discharge is carried out at a bath temperature in the range of from 15 to 60°C and a current density in the range of from 1 to 5 A/dm<sup>2</sup> for 10 to 60 minutes.

12. A method according to any preceding claim wherein the metal substrate on which the ceramic film is formed comprises aluminium or alloys thereof; zirconium, titanium, niobium, magnesium or alloys thereof.

13. A method for forming a ceramics film on the surface of a substrate by spark discharge performed in an electrolytic bath wherein the electrolytic bath comprises an aqueous solution of a water-soluble silicate or colloidal silicate and/or an oxyacid salt, in which solution fine particles comprising particles of molybdenum disulfide, carbon, fluorinated graphite or tetrafluoroethylene resin are dispersed and wherein the spark discharge is carried out in the electrolytic bath while ensuring that the fine particles are maintained in suspension in the bath.

14. A method according to claim 13 wherein the particle size of the fine particles is in the range of from 0.01 to 100 $\mu$ m.

15. A method according to claim 14 wherein the particle size of the fine particles is in the range of

from 0.03 to 20 $\mu$ m.

16. A method according to claim 13, 14 or 15 wherein the spark discharge is carried out at a bath temperature in the range of from 5 to 90°C and at a  
5 current density in the range of from 0.2 to 20 A/dm<sup>2</sup> for not less than 5 minutes.

17. A method according to claim 16 wherein the spark discharge is carried out at a bath temperature in the range of from 15 to 60°C and at a current density  
10 in the range of from 1 to 5 A/dm<sup>2</sup> for 10 to 60 minutes.

18. A method according to any of claims 13 to 17 wherein the amount of the fine particles added to the electrolytic bath is in the range of from 5 to 100 g/l.

19. A method according to any of claims 13 to 18  
15 wherein the metal substrate on which the ceramic film is formed comprises aluminium or alloys thereof; zirconium, titanium, niobium, magnesium or alloys thereof.

20. A method according to any of claims 13 to 19 wherein the ceramic to be added to the aqueous solution comprises Al<sub>2</sub>O<sub>3</sub>, Al(OH)<sub>3</sub>, SiO<sub>2</sub>, 3Al<sub>2</sub>O<sub>3</sub> · 2SiO<sub>2</sub>, TiO<sub>2</sub>, ZrO<sub>2</sub>, Cr<sub>2</sub>O<sub>3</sub>, SiC, TiC, TiN, TiB, ZrB, BN, WC, WSi<sub>2</sub> or MoSi<sub>2</sub>.